8. Geochemical Modeling: Speciation of Dissolved Components, Mass Transfer Processes, and Calculation of Solution Saturation with Respect to Various Mineral Phases

PRELIMINARY MODEL DEVELOPMENT OF THE GROUND- AND SURFACE-WATER SYSTEM IN PINAL CREEK BASIN, ARIZONA
Angeroth, C.E.; S.A. Leake; B.J. Wagner
U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 211-216, 1999

Ongoing studies of surface water and ground water contaminated by acidic-mine wastes in the Pinal Creek Basin near Globe, Arizona, include the development of a ground-water flow model. The flow system is being simulated with the U.S. Geological Survey's updated three-dimensional, finite-difference, ground-water flow model, MODFLOW-96. The model has been vertically discretized into five layers and horizontally discretized into 62.5-meter by 125-meter cells. Simulation of the hydrologic processes in the basin will provide information on the effects of streamflow infiltration, ground-water discharge to a perennial stream reach, ground-water pumping, and an unlined surface-water impoundment. The model also will be used to test the value of various types of data for calibrating ground-water flow models. The aquifer is bounded by impermeable crystalline rocks and is composed of a thick conglomerate and, near major drainages, unconsolidated alluvium where the bulk of the contamination is present. More Info: http://toxics.usgs.gov/pubs/wri99-4018/Volume1/index.html

ENHANCEMENTS TO THE GEOCHEMICAL MODEL PHREEQC-1D TRANSPORT AND REACTION KINETICS
Appelo, C.A.J.; D.L. Parkhurst
Proceedings, 9th International Symposium on Water-Rock Interaction (WRI-9): Rotterdam
p 873-876, 1998

REACTIVE AND NON-REACTIVE TRANSPORT MODELING FOR WIGHTMAN FORK, SUMMITVILLE MINE, COLORADO: APPLICATION OF THE OTIS/OTEQ MODEL TO A LOW-FLOW SYNOPTIC STUDY
Ball, J.W.; D.K. Nordstrom; R.L. Runkel, U.S. Geological Survey, Boulder, CO
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 125-134, ©2000

Low-flow reactive-transport processes in Wightman Fork downstream of the Summitville mine, south-central Colorado were simulated using the OTIS and OTEQ solute-transport models. The simulation was calibrated using data from a synoptic study conducted during October 1998. Discharge over the 8-km reach from just below the mine site to the Alamosa River confluence ranged from 0.077 to 0.17 m3/s; travel time was 10.7 hours; pH ranged from 4.6 to 5.7. Simulations revealed that mass balance for SO4 was maintained, and that pH, Fe, and Al were non-conservative. Simulations allowing hydrous ferric and aluminum oxide or hydroxysulfate precipitation matched observed water quality conditions more closely than simulations without precipitation.

TRANSPORT MODELING OF REACTIVE AND NON-REACTIVE CONSTITUENTS FROM SUMMITVILLE, COLORADO: PRELIMINARY RESULTS FROM THE APPLICATION OF THE OTIS/OTEQ MODEL TO THE WIGHTMAN FORK/ALAMOSA RIVER SYSTEM
Ball, J.W.; R.L. Runkel; D.K. Nordstrom
U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 305-312, 1999

Reactive-transport processes in the Wightman Fork/Alamosa River system downstream of the Summitville Mine, south-central Colorado, were simulated under low-flow conditions using the OTIS and OTEQ solute transport modeling programs. Simulation results revealed that Ca, Cu, Mg, Mn, Na, Zn, Cl, F, and SO4 are conservative in the stream reach, whereas pH, Fe, and Al are non-conservative. Simulations that allow precipitation of Fe(OH)3 and Al(OH)3 match observed water quality more closely than conservative simulations. The pH could not be adequately simulated without assuming that tributary inflows had pH values of about 8 or higher and alkalinities of 50-110 milligrams per liter (mg/L). Subsequent sampling confirmed these predictions. More Info:
http://toxics.usgs.gov/pubs/wri99-4018/Volume1/index.html

HYDROCHEMICAL MODELLING FOR PRELIMINARY ASSESSMENT OF MINEWATER CONTAMINATION
Banwart S.; M. Malmström
Journal of Geochemical Exploration (in review). 1999

PRINCIPLES OF SPECIAL MODEL CONSTRUCTION IN SOLVING PROBLEMS OF HEAVY METAL MIGRATION IN NATURAL WATERS
Belevantsev, V.I.; S.A. Sukhenko
Water Resources, Vol 221, p 77-80, 31 Jan 1995

A system of methodological principles for constructing models of the heavy metal state in natural water solutions is formulated. It is based on the concepts of local and partial equilibria, as well as on the notions of “original” systems, completeness of description, degree of detailing, and expedient decompositions. The above principles are used to interpret a series of field data on the condition of surface water in the Upper Ob' Basin and, in particular, to analyze the forms of mercury occurrence in the water.

APPLICATIONS OF GEOLOGICAL BLOCK MODELS TO ENVIRONMENTAL MANAGEMENT
Bennett, M.W.; H.J. Kempton; J.P. Maley
Fourth International Conference on Acid Rock Drainage (ICARD), June 1997, Vancouver
p 293-303, 1997

Many deposits provide challenges in resource estimation that not only include the quantity of minable minerals in a deposit but also the amount and location of materials that might have implications for environmental impact during development, operation, closure and post closure/ remediation The potential for acid rock drainage (ARD) from waste material is recognized as a key issue in project planning. There are two main components of the block model: 1) estimate the acid generation potential of waste material, and 2) estimate the metal or trace element component of the waste material that would impact the metal leaching (ML) component of the ML/ARD program. A waste material estimate must be calculated in

conjunction with the resource estimate because of the importance for mine waste disposal. ARD waste material includes overburden, waste rock, pit walls, pit floor and tailings, which should be classified as acid generating (AG), potentially acid generating (PAG), potentially acid consuming (PAC) or potentially neutral (PN) for regulatory and permitting purposes. The initial ARD study should begin at the exploration stage when management deems the deposit to have the potential to be an economically feasible operation. The type of predictive ARD block model that is used should be decided by the resource practioner. It will be used in long range planning and production decisions which ultimately lead to the estimation of the disposal costs associated with a block of waste rock. This is very important since each waste block must be treated separately as to its mode of removal or salvage, placement and subsequent treatment.

GEOCHEMICAL KINETIC MODELING OF ACID ROCK DRAINAGE
Brown, P.L.; A.I.M. Ritchie; J.W. Bennett; M.J. Comarmond; G.P. Timms, ANSTO, Menai, Australia
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 289-296, ©2000

Geochemical kinetic models have only become available in recent years and their utilization in the prediction of effluent chemistry from sulfidic waste rock piles is even more recent. The models used to date, however, have incorporated some questionable assumptions. This paper shows how geochemical, mineralogical and physical field data have been coupled to remove some ill-founded assumptions in the construction of a geochemical kinetic model. Further, the paper discusses a comparison between the observed effluent chemistry from a waste rock dump at the Rum Jungle copper/uranium mine in northern Australia with model predictions. In general, there is good agreement between the two, although an anomalous result is discussed.

APPROACH USED TO PIT FILLING AND PIT LAKE CHEMISTRY ON MINE CLOSURE – VOISEY'S BAY, LABRADOR
Bursey, G.G; J.J. Mahoney; J.E. Gale; S.E. Dignard; W. Napier; D. Reihm; B.W. Downing
Fourth International Conference on Acid Rock Drainage (ICARD), 31 May 31- 6 June 1997 Vancouver, BC, Canada
MEND Secretariat CANMET, Ottawa, Ontario. p 257-275, 1997

PHREEQCI--A GRAPHICAL USER INTERFACE FOR THE GEOCHEMICAL COMPUTER PROGRAM PHREEQC
Charlton, Scott R.; Clifford L. Macklin; David L. Parkhurst
U.S. Geological Survey Water-Resources Investigations Report 97-4222, 9pp, 1997

PhreeqcI is a Windows-based graphical user interface for the geochemical computer program PHREEQC. PhreeqcI provides the capability to generate and edit input data files, run simulations, and view text files containing simulation results, all within the framework of a single interface. PHREEQC is a multipurpose geochemical program that can perform speciation, inverse, reaction-path, and 1D advective reaction-transport modeling. Interactive access to all of the capabilities of PHREEQC is available with PhreeqcI. The interface is written in Visual Basic and will run on personal computers under the Windows(3.1), Windows95, and WindowsNT operating systems. For additional information: http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqci/index.html

MODELLING OF ACID MINE DRAINAGE FROM WASTE ROCK AND MILL TAILINGS: STATE-OF-THE-ART REPORT
Destouni, G.; M. Malmström; S. Berglund; M. Lindgren
Report No 3057, Dept. of Civil and Environmental Engineering, Royal Inst. of Technology, Stockholm, Sweden, 1999

ESTIMATION OF A WASTE ROCK ARD BLOCK MODEL FOR THE WINDY CRAGGY MASSIVE SULPHIDE DEPOSIT, NORTHWESTERN BRITISH COLUMBIA
Downing,B.W.; G. Giroux
Exploration and Mining Geology, Vol 2 No 3, p 203-215, 1993

MANAGEMENT OF ACID DRAINAGE AT MINING FACILITIES USING DYNAMIC SYSTEMS MODELING (DSM)
Finley, J.B.; D.D. Runnells (Shepherd Miller, Inc., Fort Collins, CO); R.C. Ford; K.C. Benke; J.W. Danni (Cyprus Climax Metals Co., Tempe, AZ)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 2, p 1235-1242, ©2000

Steady-state water balance models have historically been used in the management of acid drainage at mine sites. Such systems could be more realistically described by non-steady-state conditions. In addition, the evaluation of alternatives for closure and management of acid drainage must consider non-steady-state conditions. Dynamic systems modeling is a method for simulating water management systems, offering flexibility in simulating either steady-state or non-steady-state conditions; allowing "what-if" scenario testing; and optimization of operation and closure alternatives. A case study is given for acidic drainage management during closure at a heap leach facility that demonstrates the utility of dynamic systems models.

MODEL CALCULATIONS FOR ACTIVE TREATMENT OF ACIDIC, IRON-CONTAINING LAKE WATER ASSUMING MINING LAKES AS CHEMICAL REACTORS
Fischer, R.; T. Guderitz; H. Reissig
Acidic Mining Lakes: Acid Mine Drainage, Limnology, and Reclamation
Springer, New York. ISBN: 354063486X. p 385-400, c1998

POTENTIAL APPLICATION OF OXYGEN-18 AND DEUTERIUM IN MINING EFFLUENT AND ACID ROCK DRAINAGE STUDIES
Ghomshei, M.M.; D.M. Allen
Environmental Geology, Vol 39 No 7, p 767-773, 15 May 2000

Oxygen-18 (18O) and deuterium (D, or 2H) are routinely used in hydrologic, climatologic and geothermal studies. In hydrology, stable isotopes provide information on the type and topology (altitude and latitude) of the recharge waters and the historical effects on water, related to such physical processes as evaporation (in ponds), melting (of snow or ice), condensation, evapotranspiration and mixing. In geothermal studies, stable isotopes provide key information related to recharge and the various temperature-dependent water/rock isotope exchange reactions. The latter is assessed through the oxygen

shift in the 18O/D correlation. At acid rock drainage (ARD) sites, water/rock interactions are primarily controlled by pH and oxidation potential. Using the isotopic characteristics of the rocks and the recharge waters as a basis, the relative oxygen shift of the ARD effluent can provide information on: (1) the residence time, (2) the rate of water/rock reactions, and (3) the actual pH at the rock/water interface. This paper offers a methodology for conducting oxygen and hydrogen isotope studies related to ARD and other mineral effluent problems. The methodology is based on: (1) comprehensive sampling of regional waters, ARD effluent and major contributing minerals and rocks, (2) isotopic and elemental analysis, and (3) data interpretation on the basis of a zero-dimensional (mass balance), multi-component mixing model.

SIMULATION OF VERTICAL TRANSPORT MINING PIT LAKE

Hamblin, P.F. (Natl. Water Res. Inst., Burlington, ON); C.L. Stevens (Natl. Inst. of Water and Atmospheric Res., Greta Point, Kilbrirnie, New Zealand); G.A. Lawrence, (Univ. of British Columbia, Vancouver, BC)

Journal of Hydraulic Engineering, Vol 125 No 10, p 1029-1038, Oct 1999

Subaqueous disposal is a technique that can, under suitable circumstances, delay or mitigate the release of material containing high levels of dissolved compounds, for example, acid rock drainage, into the surrounding environment. The technique places the material in question under a relatively inert cap of lighter fluid in a deep basin, such as that left after mining. In many situations, because of low diffusion rates, the material may be considered as being isolated from the environment. However, there are a number of naturally occurring physical mechanisms that can quite efficiently bring this material to the surface, and hence, to the surrounding environment. We describe a modeling application to a deep and steep-sided chemically stratified lake using an extended version of the lake and reservoir water quality model, DYRESM, incorporating algorithms for detailed ice cover, heat fluxes, and also internal wave-driven boundary mixing. Sheltering and shading of the meteorological forcing is taken into account in the model. Both the field data and the model confirm the capping effects of the freshwater cap (S <0.7 g/L) overlying the relatively salty water (S>0.85 g/L) in the pit. Examination of the mechanistically determined vertical eddy diffusivities suggests that at depths below the surface mixed layer, double diffusion dominates over vertical mixing due to bottom-generated turbulence stemming from basin-scale internal waves. The ability of the model to simulate for periods longer than about 6 months is not addressed in this study.

MEASUREMENT OF OXYGEN, TEMPERATURE, AND GEOCHEMICAL PROFILES IN SULFIDE AND OXIDE WASTE ROCK DUMPS OF DIFFERENT AGES

Helgen, S.; A. Davis (Geomega, Boulder, CO); C. Byrns (BHP, Ely, NV)

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 269-276, ©2000

The 4000-acre historic Robinson Mining District outside Ely, NV, hosts a continuum of oxide/sulfide waste rock dumps of different ages. In an effort to develop a paradigm to explain past, existing, and future conditions at the site, profiles of oxygen, pH, temperature, and specific conductivity were collected from various waste rock dumps using a hand-driven soil gas probe and a down-hole sampling device. The resulting data are useful in interpreting the rate and manner of pyrite oxidation within the dumps and in identifying waste rock dumps that may require remedial measures compared to those that require only minimal action prior to closure.

ROLE OF OXYGEN TRANSFER IN ACID MINE DRAINAGE TREATMENT
Hustwit, C.C.; T.E. Ackman; P.M. Erickson
Bureau of Mines, United States Dept. of the Interior. Reports of Investigations 9405. 18 pp, 1992

PREDICTION OF TRAVELTIME AND LONGITUDINAL DISPERSION IN RIVERS AND STREAMS
Jobson, Harvey E.
USGS Water-Resources Investigations Report 96-4013, 69 pp, 1996

Although many excellent models are available to estimate travel time and dispersion, none can be used with confidence before calibration and verification to the particular river reach in question. Therefore, the availability of reliable input information is usually the weakest link in the chain of events needed to predict the rate of movement, dilution, and mixing of contaminants in rivers and streams. Measured tracer-response curves produced from the injection of a known quantity of soluble tracer provide an efficient method of obtaining the necessary data. The purpose of this report is to use previously presented concepts along with extensive data collected on time of travel and dispersion to provide guidance to water-resources managers and planners in responding to spills. This is done by providing methods to estimate 1) the rate of movement of a contaminant through a river reach, 2) the rate of attenuation of the peak concentration of a conservative contaminant with time, and 3) the length of time required for the contaminant plume to pass a point in the river. Although the accuracy of the predictions can be greatly increased by performing time-of-travel studies on the river reach in question, the emphasis of this report is on providing methods for making estimates where few data are available. Four example applications are included to illustrate how the prediction equations developed in this report can be used either to calibrate a mathematical model or to make predictions directly.

GEOCHEMICAL TRANSPORT MODELING OF TAILING PORE WATER
Jordan, D.; R. Newcomer; R. MacKinnon
Fifth International Conference on Tailing & Mine Waste '98, 26-28 January, Ft. Collins, CO
p 497-506, 1998

MODELING THE RESPONSE OF LYSIMETERS
Kuo, E.Y.; A.M. Garvie; W.W. Plotnikoff, ANSTO, Menai, Australia
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 225-234, ©2000

Water infiltrating the surface of waste rock dumps transports pollutants into the environment. Lysimeters have been used to quantify the infiltration rate. To date their design has been guided by modeling under steady-state conditions. Recently a two-dimensional finite element code has been developed to model the response of lysimeters to time-dependent infiltration rates. It was used to investigate the response of lysimeters installed in a waste rock dump and subject to a monsoonal rainfall pattern. The results are presented and compared with field data.

A THREE-DIMENSIONAL, THREE-PHASE GEOCHEMICAL KINETIC MODEL FOR ACID ROCK DRAINAGE

Lin, C-K; E.M. Trujillo; W.W. White
Proceedings of the Fourth International Conference on Acid Rock Drainage, June 1997, Vancouver
American Society of Surface Mining and Reclamation, Vol 2, p 479-495, 1997

NUMERICAL MODELING OF ACID MINE DRAINAGE GENERATION AND SUBSEQUENT REACTIVE TRANSPORT
Mayer, K.U.; D.W. Blowes; E.O. Frind, Univ. of Waterloo, Waterloo, ON
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 135-142, ©2000

The multicomponent reactive transport model MIN3P can be used to simulate the evolution of pore water, pore gas, and the mineralogical composition in mine waste environments. The model is formulated for variably-saturated conditions, considers transport of dissolved and gaseous species, and describes geochemical reactions based on a partial equilibrium formulation. Reaction processes included are complexation, oxidation-reduction, ion-exchange, mineral dissolution-precipitation and gas exsolution-dissolution reactions. An example application, describing the generation of acid mine drainage and subsequent reactive transport for a 1D-vertical profile in a tailings impoundment near Elliot Lake, ON, is provided.

VARIABLY SATURATED FLOW AND TRANSPORT IN A HEAP LEACH MINING OPERATION [abstract only]
McCord, J.T.; M. Ankeny; R. Schmidt-Petersen
EOS, Transactions of the American Geophysical Union, Vol 78 No 46, F218, 1997

CRITICAL REVIEW OF GEOCHEMICAL PROCESSES AND GEOCHEMICAL MODELS ADAPTABLE FOR PREDICTION OF ACIDIC DRAINAGE FROM WASTE ROCK
MEND Secretariat CANMET, Ottawa, Ontario. MEND Report 1.42.1, Apr 1995

This report describes the geochemical processes occurring in acid-generating waste rock piles and evaluates available geochemical computer models with respect to their abilities to simulate the geochemical processes to predict the quality of acid rock drainage (ARD).

METAL TRANSPORT AND IMMOBILIZATION AT MINE TAILINGS IMPOUNDMENTS
MEND Secretariat CANMET, Ottawa, Ontario. MEND Report PA-2, Mar 1997

A new simulation model, MINTOX, has been developed to provide a useful tool for predicting the behaviour of kinetic sulphide mineral oxidation within mine tailings impoundments, and for simulating the subsequent speciation and transport of oxidation products through the tailings and into downstream aquifers. MINTOX includes the major reaction sequences known to control the hydrogeochemistry at many base metal tailings sites. These processes include diffusion of oxygen into the unsaturated zone, diffusion of oxygen into the sulphide mineral grains, sulphide mineral oxidation, acid generation and release of iron, sulphate and heavy metals. Furthermore, the model can simulate the advective-dispersive transport of the mobilized species, accounting for equilibrium speciation and reactive processes including solid mineral dissolution and precipitation. MINTOX has been tested in both one-dimensional and two-dimensional modes against observed field data from the Nordic Main tailings impoundment near Elliot Lake Ontario.

WATER QUALITY, FATE OF METALS, AND PREDICTIVE MODEL VALIDATION OF A CONSTRUCTED WETLAND TREATING ACID MINE DRAINAGE
Mitsch, W.J.; K.M. Wise
Water Research, Vol 32, p 1888-1900, 1998

MODELLING OF THE TRANSPORT OF ACID AND COPPER IN TAILINGS BASED ON THE USGS MOC MODEL
Muñoz, J.F.; J.R. Carvajal; P. Rengifo
Geo-Environmental Issues Facing the Americas, 21-23 September 1994, Mayagüez, Puerto Rico
New York: ASCE. ISBN: 0-7844-0098-9, Geotechnical Special Publication No. 47, p 126-131, 1995

SIMULATION OF ELECTRICAL POTENTIAL DIFFERENCES NEAR A CONTAMINANT PLUME EXCITED BY A POINT SOURCE OF CURRENT
Osiensky, James L.; Roy E. Williams; Dale R. Ralston; Gary S. Johnson; Leland L. Mink
Univ. of Idaho, Moscow, ID
Mine Water and the Environment, Vol 18 No 1, Apr 1999

Finite-difference simulations of electrical excitation of conductive contaminant plumes indicated that the approximate dimensions of a plume and the approximate location of its center of mass can be derived, under specified circumstances, from the resulting electrical potential fields. Direct electrical excitation of a contaminant plume by a point current source was simulated for homogenous and isotropic conditions as well as in the presence of conductive clay layers and lenses. When a very shallow water table was assumed, changes in the electrical potential field between baseline (preplume) conditions and conditions that included a developing plume graphically formed a difference dipole. Simulations suggested that electrical flow is channeled preferentially through the negative difference pole at the approximate location of the center of mass in a dispersive contaminant plume. Electrical flow was channeled directly through the negative difference pole at the terminal end of a conductive clay lens. Simulations showed that even in the presence of conductive clays, the approximate location of the center of mass of an evolving contaminant plume could be delineated. This illustrates the potential future value of this approach, assuming continued technological advances in the field.

GEOCHEMICAL MOLE-BALANCE MODELING WITH UNCERTAIN DATA
Parkhurst, D.L.
Water Resources Research, Vol 33 No 9, p 1957-1970, 1997

MODELING REMOVAL OF CD, CU, PB, AND ZN IN ACIDIC GROUNDWATER DURING NEUTRALIZATION BY AMBIENT SURFACE WATERS AND GROUNDWATERS
Paulson, Anthony J.; Laurie Balistrieri
Environmental Science & Technology, Vol 33 No 21, p 3850- , 01 Nov 1999

Simulations and experiments demonstrate that the stage of acid neutralization at which acid-rock drainage enters surface waters significantly affects the removal of Pb, Cu, Z, and Cd.

PREDICTING AQUEOUS METAL SPECIES IN A STREAM IMPACTED BY MINING ACTIVITY
Pitt, J.L. (U.S. EPA, Kansas City, KS), R.Y. Surampalli; N.H. Crisp; L.C. Ferrington, Jr., (Kansas Biological Survey, Univ. of Kansas, Lawrence)
Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, Vol 2 No 4, p 166-171, Oct 1998

The impact of mining activity in the Tri-State Mining District of Missouri, Kansas, and Oklahoma,as resulted in continual exceedance in water quality standards in many surface waters including Short Creek in Galena, Kan. Critical heavy metals detected in short Creek have been lead, cadmium, and zinc. Water column samples were collected at each of seven sites from May 1992 to May 1995 and were analyzed for temperature, pH, conductivity, and total $PO4^{3-}$, $CO3^{2-}$, Ca^{2+}, Mg^{2+}, Na^{+}, $SO4^{2-}$, Ba^{2+}, Cd^{2+}, Pb^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Al^{3+}, and Zn^{2+}. Using MINTEQ, probable concentrations of metal species were predicted to evaluate the potential for metals to be in a bioavailable form. The MINTEQ predictions demonstrated the presence of dissolved metals, including a dominant free metal ion. Aqueous components within the dissolved fraction predicted using MINTEQ offered a unique understanding of the critical factors that may determine toxic aqueous conditions.

ATMOSPHERIC OXIDATION OF THE PYRITIC WASTE ROCK IN MAARDU, ESTONIA. 1 FIELD STUDY AND MODELLING
Puura, E.; I. Neretnieks; K. Kirsimä
Environmental Geology, Vol 39 No1, p 1-19, 22 Nov 1999

A field survey and modelling of the oxidation and carbonate buffering reactions inside the alum-shale-containing waste rock dumps located in Maardu, Estonia, was accomplished. In the slope areas, the shale has been altered at high temperatures due to the spontaneous combustion and the pyritic acidity has been eliminated through migration of SOx gases out from the dump. In the central parts of the waste rock plateaus, low temperature pyrite oxidation fronts develop towards the dump depth and towards the centres of individual shale lumps. The main secondary phases precipitating in the weathering profile are gypsum, ferric oxyhydroxide, K-jarosite and smectite. The respective field data made it possible to calibrate the two-stage oxygen diffusion model and the characteristic pyrite oxidation rate 0.06-0.08 mol of pyrite reacted per kg of available water (pyrox/H2O value) was estimated to describe the first tens of years of dump performance. The model is capable to compare different shale disposal strategies that are illustrated with two case scenarios. The buffering of sulphuric acid by Mg-calcite appears to be an incongruent reaction with gypsum precipitating that leads to the build-up of the high Mg/Ca ratio in the leachate. Application of the Mg/Ca method estimates the pyrox/H2O value in the range of 0.05-0.14 mol/kg.

GEOMETRIC AND PHYSICO-CHEMICAL PROPERTIES DETERMINING SULFIDE OXIDATION RATES IN WASTE ROCK DUMPS
Ritchie, A.I.M. (Aldgate, South Africa); P. Miskelly (ANSTO, Menai, Australia)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 277-288, ©2000

The 2-D code FIDHELM has been used to simulate conditions in piles of pyritic material with vertical dimensions of 20 to 70 meters and a horizontal dimension of 500 meters. Those properties of the pile and its external environment (wind, temperature) important in determining the time and space dependence of sulfide oxidation, have been identified. A prescription to evaluate the overall sulfide

oxidation rate in a pile of known volume but variable geometry has been developed.

MODELING SOLUTE TRANSPORT AND GEOCHEMISTRY IN STREAMS AND RIVERS USING OTIS AND OTEQ

Runkel, R.L.(U.S. Geological Survey, Denver, CO); K.E. Bencala; B.A. Kimball

U.S. Geological Survey Toxic Substances Hydrology Program: Proceedings of the Technical Meeting, 8-12 March 1999, Charleston, South Carolina. Volume 1: Contamination From Hard-Rock Mining
U.S. Geological Survey Water-Resources Investigation Report 99-4018A, p 109-118, 1999

Solute transport in streams is governed by a suite of hydrologic and geochemical processes. Interactions between hydrologic processes and chemical reactions may be quantified through a combination of field-scale experimentation and simulation modeling. Two mathematical models that are used to simulate solute transport in streams are presented here. A model that considers One-dimensional Transport with Inflow and Storage (OTIS) may be used in conjunction with tracer-dilution methods to quantify hydrologic transport processes (advection, dispersion, and transient storage). Additional applications of OTIS include analyses of nonconservative solutes that are subject to sorption processes and (or) first-order decay. A second model, OTEQ (One-dimensional Transport with EQulibrium chemistry), combines the transport mechanisms in OTIS with a chemical equilibrium submodel that considers complexation, precipitation/dissolution, and sorption. OTEQ may be used to quantify the geochemical processes affecting trace metals. More Info: http://toxics.usgs.gov/pubs/wri99-4018/Volume1/index.html

HYDROLOGICAL CHARACTERIZATION OF A SULFIDE WASTE ROCK DUMP

Saretsky, G.T. (Stantec Consulting Ltd., Saskatoon, SK); G.W. Wilson (Univ. of Saskatchewan, Saskatoon, SK)

Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 205-214, ©2000

A comprehensive hydrologic study was completed for the waste rock dump at Equity Silver mine, BC. Characterization of the hydrollogic system included geologic structure, topography, surface hydrology and groundwater systems. The results of the study conclude that the cover system is restricting net infiltration to approximately 5%. However, significant discharge continues to occur from the perimeter of the dump. A three dimensional seepage analysis carried out to illustrate the influence of groundwater discharge associated with the regional topography and geologic structures. The results of the modeling program show that groundwater discharge occurs from the waste rock dumps when high recharge rates are specified for the surrounding topography. This groundwater discharge is strongly influenced by the high hydraulic conductivity assumed for the fractured bedrock. The modeling results are considered preliminary and field drilling and piezometer installation is being conducted to determine the groundwater regime in the vicinity of the waste rock dump.

MODELING THE TRANSPORT AND FATE OF COPPER IN KESWICK RESERVOIR, SHASTA COUNTY, CALIFORNIA
Saviz, C.M.; G.T. Orlob; I.P. King
Environmental and Coastal Hydraulics: Protecting the Aquatic Habitat. Theme B: Water for a Changing Global Community. The 27th Congress of the International Association for Hydraulic Research, 10-15 August 1997, San Francisco, CA
New York: ASCE. ISBN: 0-7844-0272-8, p 21-26, 1997

GEOENVIRONMENTAL MODELS FOR SEAFLOOR BASE- AND PRECIOUS-METAL MASSIVE SULFIDE DEPOSITS
Seal, R.R., II; J.M. Hammarstrom; N.K. Foley (U.S. Geological Survey, Reston, VA); C.N. Alpers (U.S. Geological Survey, Sacramento, CA)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 151-158, ©2000

Geoenvironmental models are compilations of geologic, geochemical, and hydrologic information that describe both the pre- and post-mining environmental signatures of mineral deposits. The environmental behavior of seafloor massive sulfide deposits varies according to deposit type. This study has divided massive sulfide deposits into six categories: 1) Noranda-type, 2) Kuroko-type, 3) Cyprus-type, 4) Bathurst-type, 5) Besshi-type, and 6) sedimentary-exhalative deposits. In addition to Fe and Al, the heavy metals most commonly associated with drainage from these deposits are Cu, Zn, Cd, Pb, and As. Metal ratios of mine drainage and natural background waters tend to reflect the primary character of the ores. Variations in pyrite and pyrrhotite contents are reflected in lower pH values associated with pyrite-rich deposit types.

PREDICTIVE DOUBLE-LAYER MODELING OF METAL SORPTION IN MINE-DRAINAGE SYSTEMS
Smith, Kathleen S.; James F. Ranville; Geoffrey S. Plumlee, et al.
Adsorption of Metals by Geomedia : Variables, Mechanisms, and Model Applications
Academic Press, San Diego, CA. ISBN: 012384245X. Chapter 24, 1998

USE OF COMPUTER MODELS TO PREDICT METAL MOBILITY IN MINE-DRAINAGE SYSTEMS: THE IMPORTANCE OF MATCHING GEOCHEMICAL CONDITIONS
Smith, Kathleen S. (U. S. Geological Survey, Denver, CO)
Geological Society of America 28th Annual Meeting, Abstracts with Programs, Vol 28 No 7, p 528, 1996

DEVELOPMENT OF AN ACID MINE DRAINAGE MODEL
Trujillo, E.M.; C.-K. Lin; S. Leonora
Univ. of Utah, Salt Lake City
Final report to the U.S. Bureau of Mines, Dept. of the Interior, Oct 1994

DEVELOPMENT OF AN ACID MINE DRAINAGE MODEL - II

Trujillo, E.M., C.-K. Lin, F. Guard
University of Utah, Salt Lake City
Final report to the U.S. Bureau of Mines, Dept. of the Interior, Aug 1996

APPLICATION OF THE SOLUTE-TRANSPORT MODELS OTIS AND OTEQ AND IMPLICATIONS FOR REMEDIATION IN A WATERSHED AFFECTED BY ACID MINE DRAINAGE, CEMENT CREEK, ANIMAS RIVER BASIN, COLORADO
Walton-Day, K. (U.S. Geological Survey, Lakewood, CO); R.L. Runkel (U.S. Geological Survey, Denver, CO); B. Kimball (U.S. Geological Survey, Salt Lake City, UT); K.E. Bencala (U.S. Geological Survey, Menlo Park, CA)
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 389-400, ©2000

The solute-transport model OTIS and the reactive solute-transport model OTEQ were used to simulate geochemical conditions in Cement Creek, a tributary to the Animas River in Colorado. OTIS was used to depict instream zinc concentrations, and to simulate the effects of two remediation scenarios on zinc concentrations at the mouth of Cement Creek. These simulations do not account for effects of changing stream pH on metal concentrations. Preliminary simulations using OTEQ to account for in-stream pH changes were unsuccessful due to the spatial nature of mixing processes, and insufficient information about the thermodynamic properties of precipitates forming in mixing zones.

CHEMICAL PREDICTIVE MODELING OF AMD FROM WASTE ROCK: MODEL DEVELOPMENT AND COMPARISON OF MODELED OUTPUT TO EXPERIMENTAL DATA
White, B., E. M. Trujillo, C.-K. Lin
Proceedings of the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, American Society of Surface Mining and Reclamation, Vol 1, p 157-166, 1994

NUMERICAL MODELING OF VERTICAL AND INCLINED WASTE ROCK LAYERS
Wilson, J.A.; G.W. Wilson; D.G. Fredlund, Univ. of Saskatchewan, Saskatoon, SK
Fifth International Conference on Acid Rock Drainage, 20-26 May 2000, Denver, CO
Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 257-268, ©2000

Conventional disposal of waste rock results in the construction of benches with fine and coarse layers dipping at the angle of repose. This interbedded structure influences flow pathways within the waste rock. A numerical modeling program was conducted to study a four-layer system consisting of alternating fine and coarse waste rock. The system was inclined from the vertical to 45 degrees with heights varying from 1-20m. The results show the effects of gravity as preferential flow developed under unsaturated flow conditions.

MULTIDIMENSIONAL SPATIAL MODELING OF THE MAY DAY MINE WASTE PILE, SILVERTON, CO

Yager, D.B.; M.R. Stanton, U.S. Geological Survey, Denver, CO

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Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, CO. ISBN: 0-87335-182-7. Vol 1, p 297-301, ©2000

Integration and synthesis of mine-site topography, geophysical, and geochemical data yields both two-dimensional and three-dimensional perspective models for the May Day mine located in the Cement Creek drainage near Silverton, CO. Induced polarization geophysical data are spatially registered with geochemical data acquired from drill hole cuttings that are contoured in three-dimensional space, thereby permitting determination of the most metalliferous and sulfur rich
zones of a waste pile. This spatial modeling application was developed to be a visually intuitive tool to aid in mine waste reclamation.